7
PRINCIPLES OF OPERATION

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CONTENTS

FIGURES

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7.1 GENERAL DESCRIPTION

Laser oscillation is obtained in both copper and gold vapour laser systems through electron collisional excitation of atomic copper or gold present as a minority species in a high speed, longitudinal discharge in a buffer gas of neon. The conversion efficiency of electrical power into laser power is approximately 1% for the copper laser and 0.2% for the gold laser. The remaining 99% of the electrical input power to the laser discharge is converted into heat which is used to maintain the laser discharge tube temperature at around 1500°C. As a result, a significant partial pressure of metal vapour is created in the discharge region by the charge of elemental copper or gold which resides in the laser discharge tube. Laser output is observed approximately 30 minutes after the laser has been switched on, as the discharge tube must be heated to a temperature where the partial pressure of metal vapour is sufficient to allow laser action. It should be noted that, if the discharge in the laser is temporarily halted by the user at any time, the discharge tube will start to cool down. In this situation, there will be a further delay, dependent on how long the discharge has been off, before full laser output power is re-established.

The fast pulsed discharge serves a dual purpose: maintenance of a sufficient, but not excessive, vapour pressure of copper or gold, and provision of sufficient electrical pulse energy to excite the copper or gold atoms to the upper laser level. This results in a relatively narrow range of average electrical input power at which reliable operation of the laser may be achieved. The limits of this power input range are controlled automatically by the PSU. It is worth noting, however, that a number of factors influence the total power deposited in the discharge volume: the laser voltage, the laser current, and the pulse repetition frequency. There is only one significant difference between the operation of the copper vapour laser and the gold vapour laser: the AU2-A operates with a smaller bore diameter tube in order that a higher temperature may be maintained for about the same electrical input power. A higher temperature is needed in gold to obtain a partial pressure of metal vapour suitable for laser action to occur: this is illustrated in Figure 7.1.

The simplicity of the laser head and the inclusion of power stabilising circuitry leads to stable output power. Furthermore, the measures which have been taken to protect the thyratron switch used in the discharge circuit ensure that operating costs are low and continuous operation in excess of 1000 hours is possible before servicing is necessary. Performance specifications of the lasers are given in Section 8.2 (see also warranty on page iii et. seq.). It should be noted that many of the novel features of Oxford Lasers' devices are subject to worldwide patents.

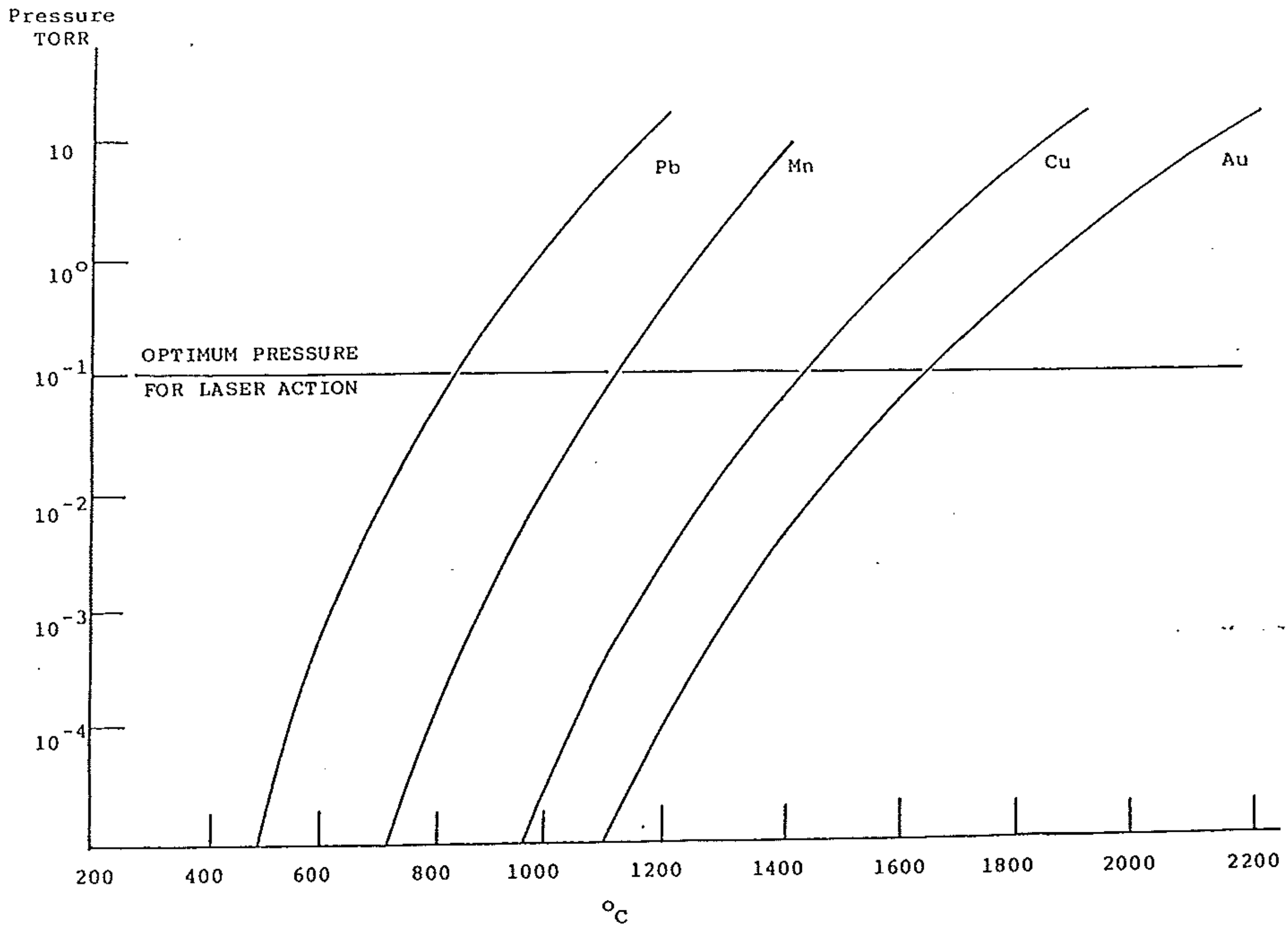


Figure 7.1 Vapour pressures of various metals as a function of temperature

7.2 THE PHYSICS OF OPERATION OF METAL VAPOUR LASERS

The key to the efficient operation of copper and gold vapour lasers lies in the configuration of the atomic energy levels of these elements (Figure 7.2). Other metals, including lead and manganese, can also be made to lase, but the differences in their structures means that their operation on any one transition is far less efficient than either copper or gold.

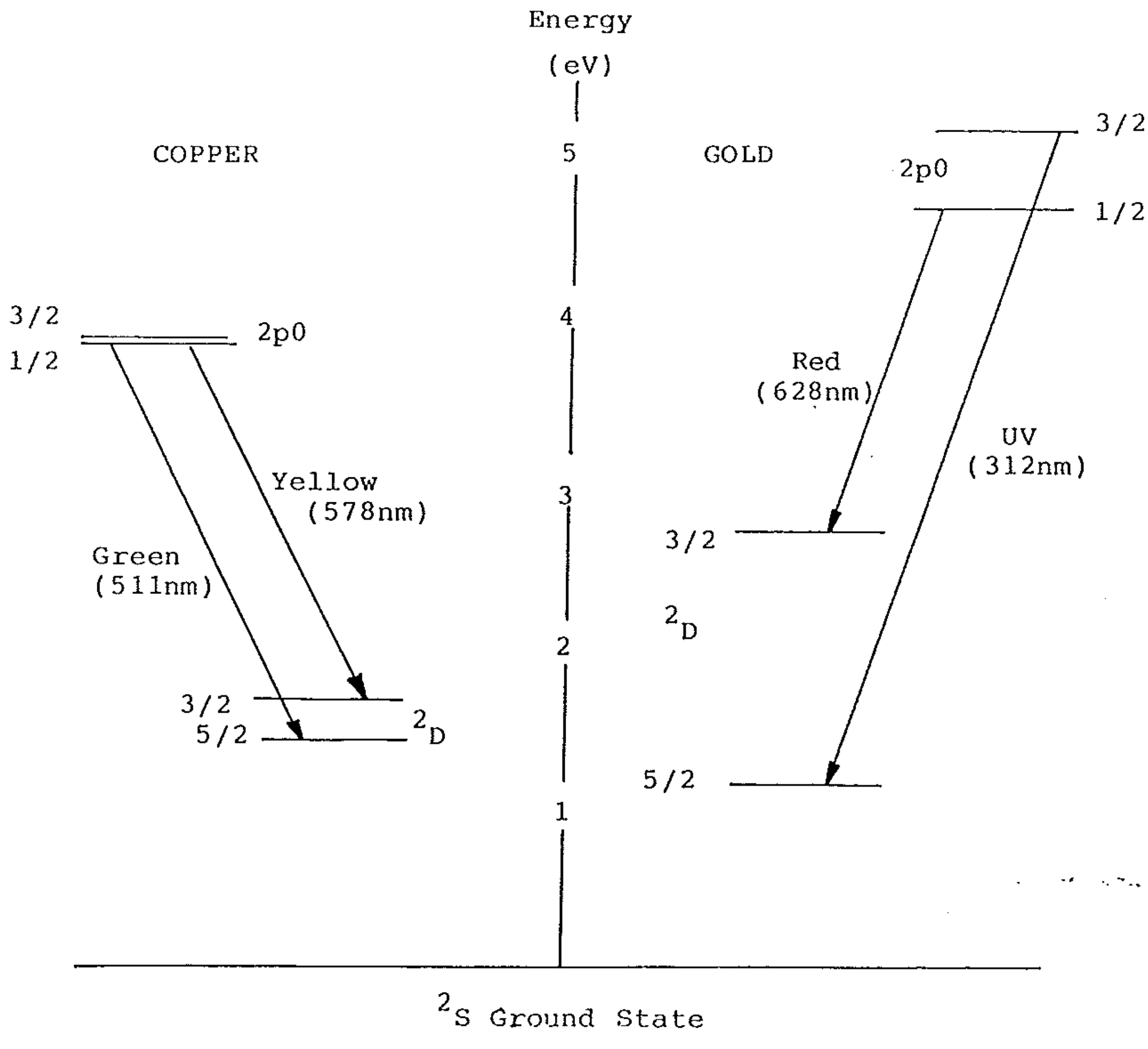


Figure 7.2 Energy level diagram for copper and gold

Laser operation is obtained by stimulated emission from the upper laser levels to the lower metastable levels of the atoms. Therein lies both the secret of the efficiency of metal vapour lasers and the reason for their inherently pulsed - rather than continuous wave (CW) - laser output.

Lasing occurs only when a situation known as a population inversion exists: the number of atoms in each of the excited upper laser level states exceeds those in each of the lower states. This is a necessary but not sufficient condition. In addition, the magnitude of the inversion must be sufficient for there to be a net gain in the laser cavity over all loss mechanisms.

In a CW laser, the lifetime of the lower laser level is such that an electron making a transition to it from the upper laser level rapidly experiences a further decay to an even lower energy level: the magnitude of the inversion can therefore be maintained on a continuous basis. In cyclic metal vapour lasers, the lower laser level is metastable: this means that lifetime against decay of atoms in this state is relatively long. Maintenance of a population inversion, and hence laser output, on a continuous basis is therefore not possible. The laser must be pulsed, and the inter-pulse period must be long enough for the population of the lower laser levels to be sufficiently reduced. It is found experimentally that the optimum PRF for a copper vapour laser increases as the laser tube bore is reduced.

The efficiency (laser power out for a given electrical power input) of CW lasers operating in the visible region of the spectrum is generally poor: an argon-ion laser has a wall plug efficiency of less than 0.1%. This low efficiency is due to a large degree to the large number of transitions that occur in addition to the laser transition. In the copper vapour laser, the wall plug efficiency approaches 1% because much less energy is wasted in pumping ancillary energy levels.

7.3 THE IMPORTANCE OF HEAT BALANCE IN THE LASER

7.3.1 The Dual Role of the Longitudinal Discharge

The longitudinal discharge in these lasers has two functions:

1) Heating the charge of copper or gold in the plasma tube to obtain a significant vapour pressure of atomic metal.

2) Exciting the copper or gold atoms to the upper laser level via electron impact.

7.3.2 Balancing Plasma Tube Temperature with Excitation of the Metal

From the preceding paragraph, it might seem that all that is required to maximise the mean laser output power from a metal vapour laser is to continue increasing the electrical input power: this will raise the temperature of the plasma tube and therefore increase the vapour pressure of metal available for excitation by a more intense excitation pulse. In practice, the situation is a little more complex: for a given laser system, there is a maximum electrical input power per unit volume beyond which the mean laser output power starts to decrease. Figure 7.3 shows the temperature of the plasma tube as a function of time from cold start, at two different electrical input powers for the larger model CU25 laser, but the general trends are the same in the CU10-A, CU15-A and AU2-A lasers.

There have been a number of reasons put forward for this turnover in laser output as the temperature of the plasma tube is increased. Recent experimental and theoretical work has led to the following explanation of the dependence of laser power on tube temperature. At a plasma tube temperature below 1250°C, the magnitude of the population inversion achieved provides insufficient gain to overcome the losses in the cavity, and no laser output is observed. As the tube temperature increases, the metal vapour density increases. The population inversion remains a constant fraction of the copper density, so, as the tube temperature increases, the threshold for lasing is crossed and lasing action occurs. At higher temperatures, the output is roughly proportional to the copper density until the plasma tube reaches about 1400°C. At this point, the copper density is approximately 1% of the buffer gas density and the metal atoms begin to affect the properties of the discharge. The presence of a large number of copper atoms in the discharge drops the average energy of the electrons, and a population inversion becomes increasingly difficult to achieve, thus reducing the output. A further limiting mechanism at

higher temperatures is the increasing loss of inversion due to increasing thermal population of the lower laser levels. The result of both these effects is the relatively narrow band of input power to achieve optimum output from the laser.

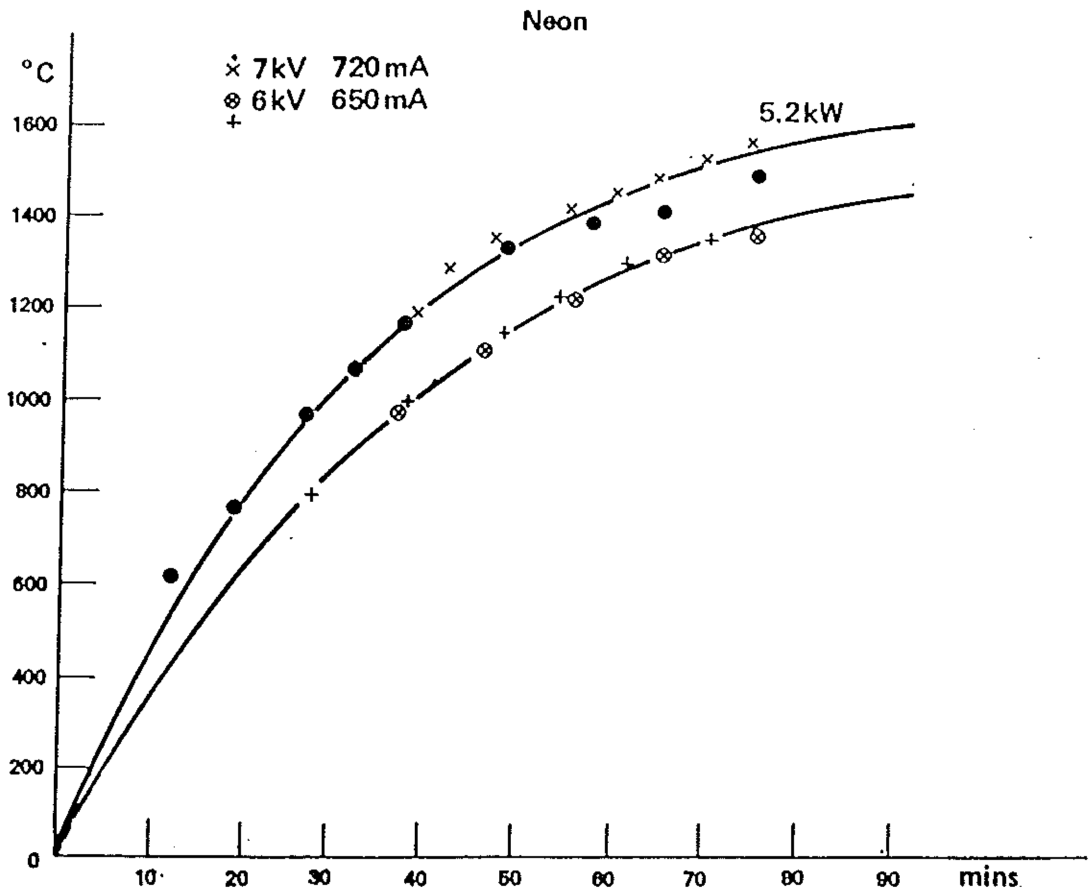


Figure 7.3 Laser plasma tube temperature against time

7.4 FACTORS AFFECTING HEAT BALANCE IN THE LASER

The running conditions of the copper and gold auto-control lasers can be varied to some extent by using a wide range of pulse repetition frequencies. It should be noted that optimum running conditions are maintained by the PSU within the main part of the available PRF range, and that operation outside of the optimum PRF range can be selected as described in Section 7.4.2.

The laser voltage, pulse repetition frequency and buffer gas pressure all affect the heat balance in a metal vapour laser by changing the electrical power input. In the auto-control lasers, only the pulse repetition frequency can be varied by the user: the other factors are maintained at optimum levels by the PSU.

Several diagrams have been included in this chapter to show the effect of varying the running parameters

of a typical copper vapour laser operating at around 20 to 30 Watts output power. Although the same parameters are not necessarily adjustable in the auto-control lasers, the diagrams help to show the reasoning behind the optimum settings which are achieved by the PSU.

7.4.1 The Effect of Plasma Tube Temperature on the Green/Yellow Ratio

The variation in total output power as a function of plasma tube temperature at two different pressures of the neon buffer gas is shown in Figure 7.4. A useful indicator of the plasma tube temperature in copper vapour systems is the green/yellow ratio of the laser output. At high temperatures, the yellow line will begin to dominate the laser output. This is illustrated in Figure 7.5.

> Note: In gold vapour systems, there is no such useful indicator of the temperature of the plasma tube.

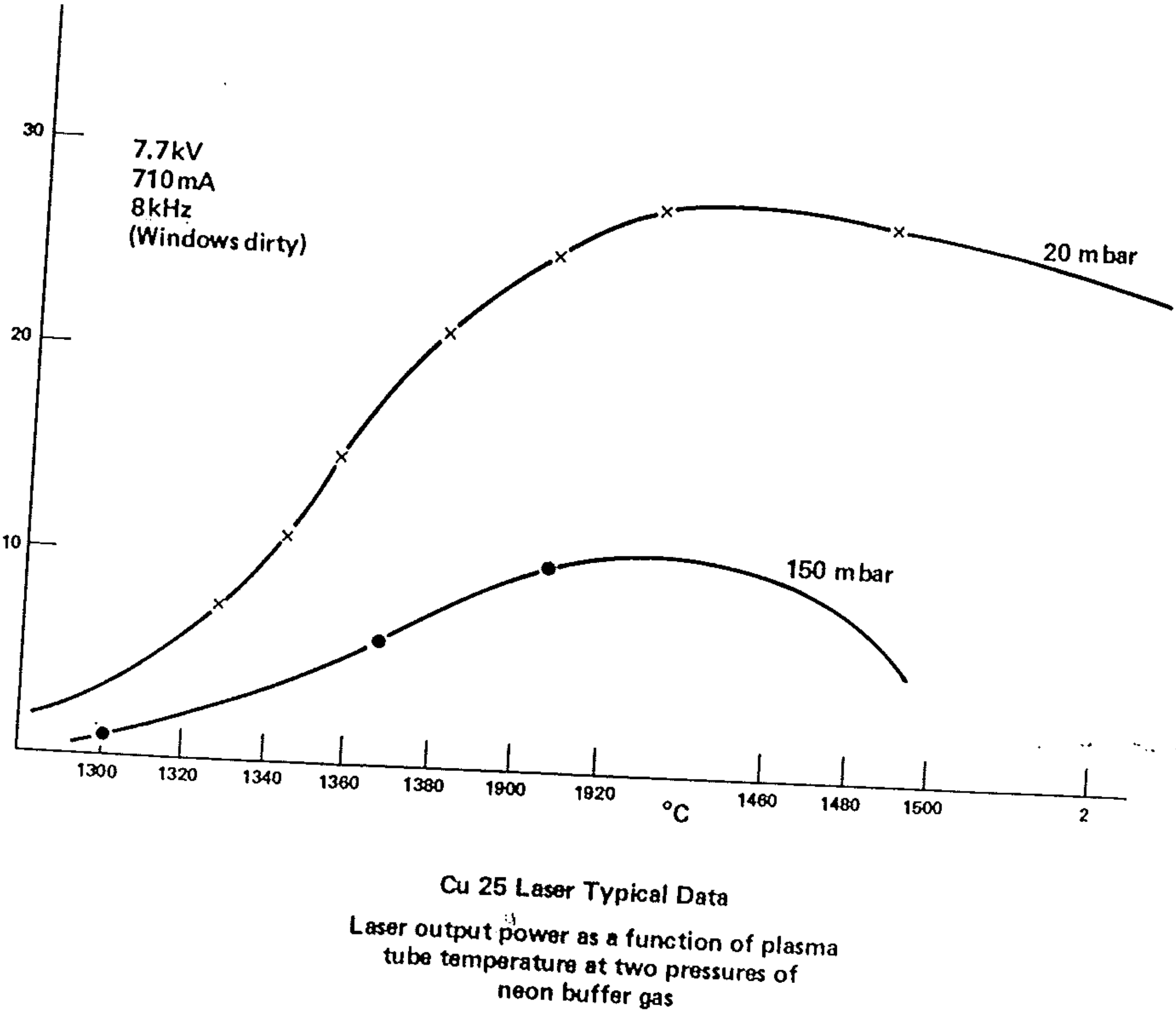
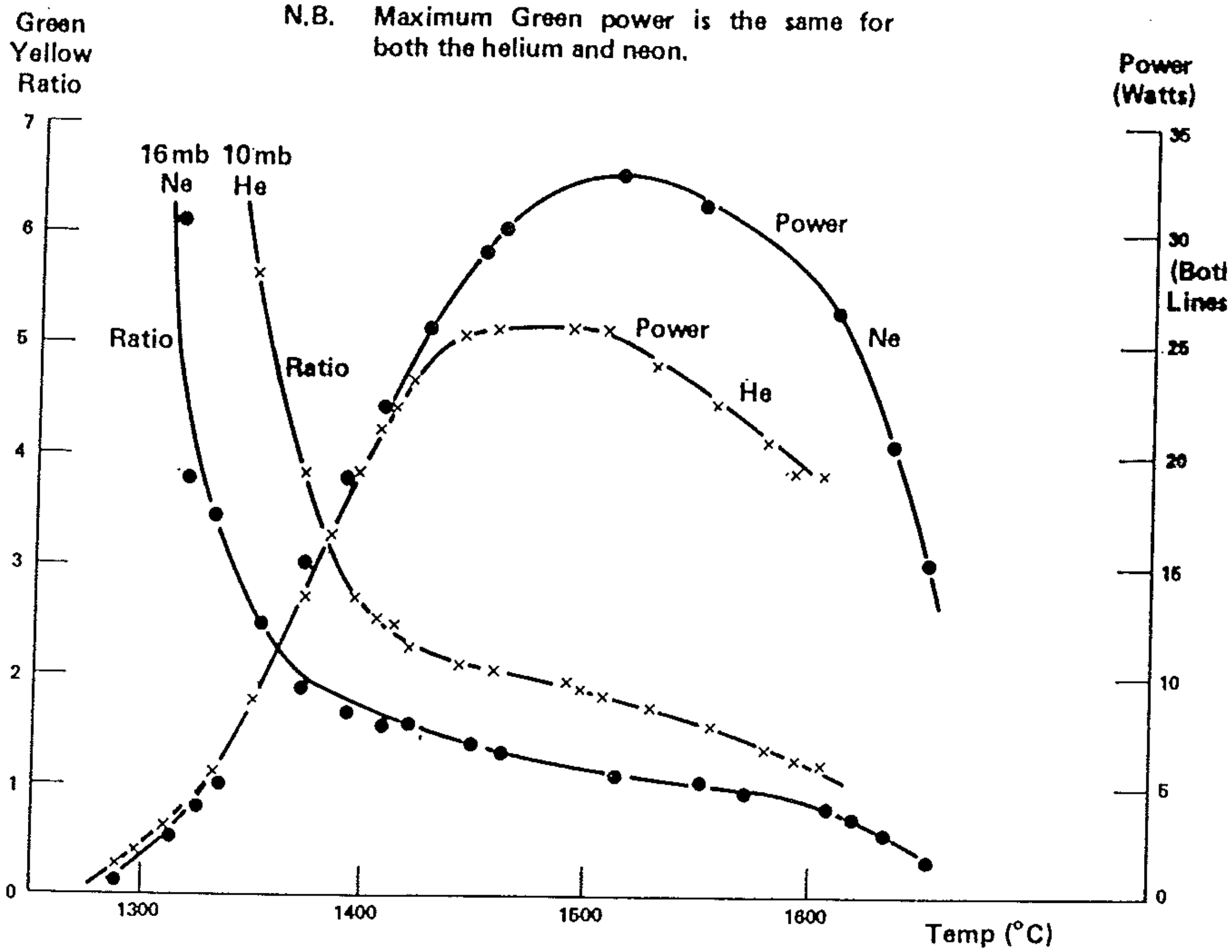


Figure 7.4 Output power against plasma tube temperature (Ne)



Cu 25 Laser Typical Data

Green/yellow ratio as a function of plasma tube temperature

Figure 7.5 Green/yellow ratio against plasma tube temperature

7.4.2 Varying the Pulse Repetition Frequency (PRF)

The PRF can be varied over quite a wide range of values. (Section 8.2 defines the PRF range for each model.) Usually this range is restricted to between 8kHz and 14kHz, although the laser can be set to run at frequencies as low as 2kHz or as high as 20kHz. Operation of the laser outside the normal range causes the **OUT OF RANGE** indicator to light, showing that a PRF has been chosen that is too high or too low for optimum stable output. Operation for extended periods in the **OUT OF RANGE** condition may affect the heat balance in the laser and thus lead to a decline in output power.

A change in the PRF has a direct result on the laser current. Consequently, any change in the pulse repetition frequency will usually cause the PSU to automatically adjust the laser voltage in order to maintain the level of electrical input power. Increases in PRF cause a reduction in both the laser pulse energy and duration, whereas decreases in PRF cause an increase in both laser pulse energy and duration for a given electrical power input. These effects are shown in Figures 7.6 and 7.7.

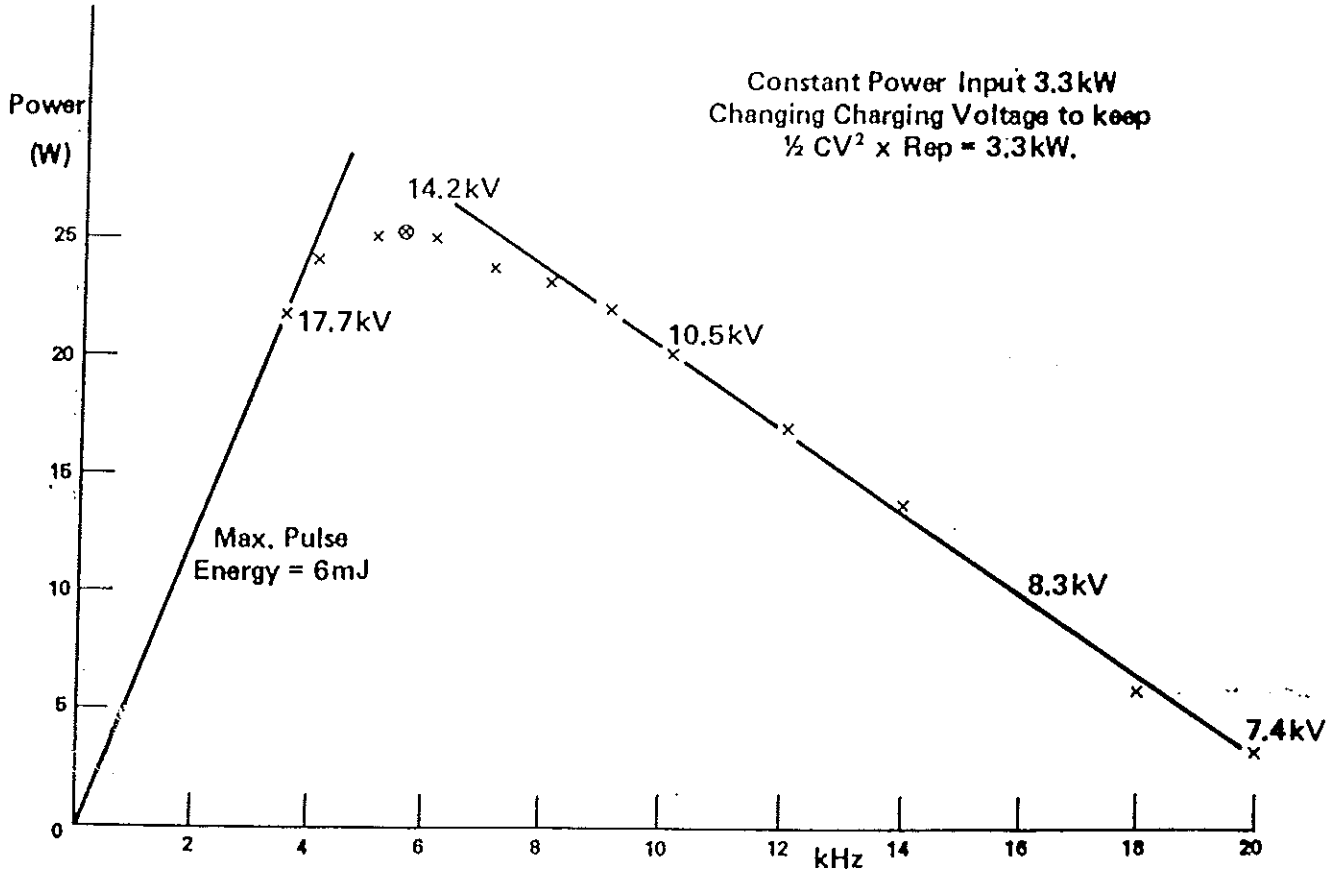
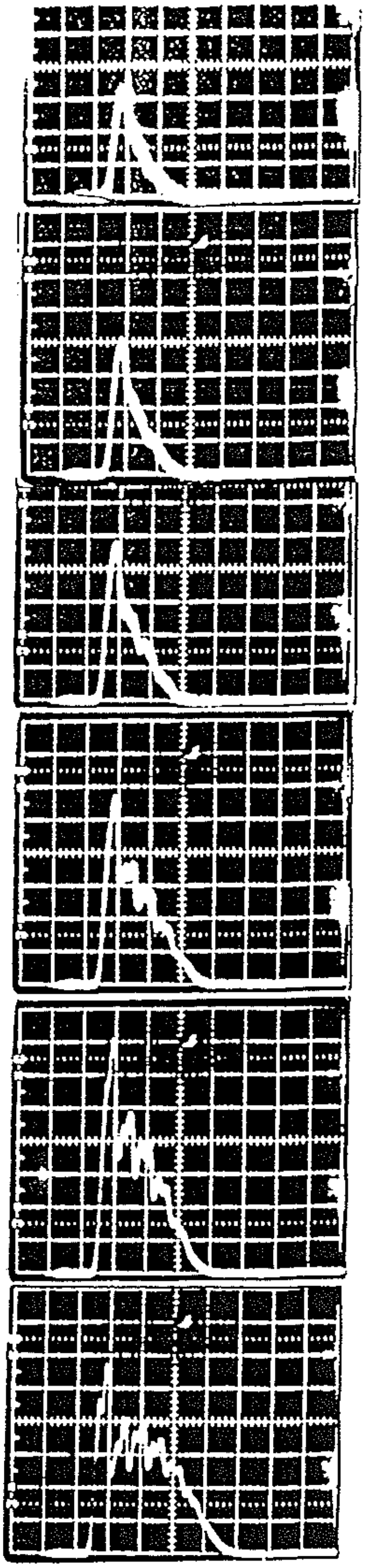


Figure 7.6 Output power against pulse repetition frequency (PRF)



9 kHz

8 kHz

Time = 20 ns/division

7 kHz

6 kHz

5.5 kHz

3 kHz

Figure 7.7 Laser pulse duration and shape against PRF

7.4.3 Buffer Gas Pressure, Cleanliness and Gas Flow

The required operating pressure of the neon buffer gas is controlled automatically by the PSU. The starting pressure of 10mbar settles at around 30mbar to 60mbar during steady running. Operation of the laser at very low gas pressures for any length of time would result in shorter metal load lifetimes, because diffusion to the cool ends of the plasma tube would be easier. It would also be found that the output windows would require more frequent cleaning.

It is most important that the laser head is free from air and moisture for correct operation. Contamination of the laser head will occur each time it is opened for servicing operations. The basic rule when carrying out service procedures is to minimise contamination.

In normal use, the laser requires a slow gas flow in order to remove residual contaminants which are emitted by the materials inside the laser tube when the laser is hot. At installation, the gas flow rate is set at about 0.5 litre-atm/hour, which in the models CU10-A, CU15-A or AU2-A results in a pressure rise in the laser of about 1mbar/minute. As the laser is used for longer periods without breaching, the integrity of the vacuum system is improved because residual outgassing decreases.

7.5 MAXIMISATION OF THYRATRON LIFE

The guaranteed life of the CX1535 EEV hydrogen thyratron installed in Oxford Lasers' models CU10-A, CU15-A and AU2-A lasers is 1000 hours (see page iii et. seq.). This no-quibble guarantee which is offered by Oxford Lasers is considerably more generous than that offered by the thyratron manufacturers, English Electric Valve Co. However, it is expected that a customer will obtain around 2000 hours of trouble-free operation from a thyratron.

The factors which affect thyratron life are: total power handled, PRF, the life of the hydrogen reservoir, and the magnitude of any reverse voltage and current. With the exception of PRF variation, these factors are optimised by the control functions within the PSU in order to maximise thyratron life.